*Keynote Presentation*

# On Effective Efficiency of Thermal Energy Conversion & Conservation

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## Overview





## Self Introduction

- B.Sc. Engg. (Mech), BUET, Dhaka, Bangladesh (1993)
- Ph.D. The University of Leeds, Leeds, UK (1998)
- Professor, Mechanical Engineering, BUET (2004)
- Professor (Grade 1), Mechanical Engineering, BUET (2018)
- Director, Centre for Energy Studies, BUET (2012 - 2014)
- Head, Dept. of Mechanical Engineering, BUET (2014 - 2016)
- Certified Energy Auditor, The Association of Energy Engineers, Atlanta, USA.
- Head of Delegation, ISO ISO/PC 248 meetings: 23 Sept - 4 Oct 2013, Stockholm, Sweden, and 14-21 Feb 2014, and 19 - 23 Jan 2015, Berlin, Germany
- Team Supervisor, Asia-Pacific Robot Contests (ROBOCON 2005-2009) in Beijing 2005, Kualalampur 2006, Hanoi 2007, Pune 2008 and Tokyo 2009.



## Significance of Effective Use of Energy Resources

Efficiency in energy conversion, as well as an increase in the effective use of renewable energy and waste heat, are critical for ensuring energy security, enhancing industrial productivity, mitigating the effects of global warming, and fulfilling UN's SDG 7[1].

[1] 7000.

- During conversion to useful work, around half of the primary energy is lost as 'waste heat' and 40% of the lost heat is in the temperature ranging from 80°C to 300°C[2].
- Waste heat is defined as 'waste heat as a resource is exergy that unavoidably leaves a process or is lost within it independent of the technological choices made within the process'[3].
- Effective utilization of waste heat boosts overall system performance with simultaneous reduction in primary energy consumption and carbon footprint[4].

[2] 6775.
[3] 4213.
[4] 5021.





## Efficiency Indicators

Efficiencies based on first-law of thermodynamics fall into 2 categories[5]:

1. 'Thermal efficiency', which compares the desired energy output to the required energy input, that is,

$$\eta_{th} \equiv \frac{\text{Energy out in product}}{\text{Energy in}}$$

where, the term *product* may refer to shaft work or generated electricity, some desired combination of heat and work etc.

2. 'First-law efficiency' or 'isentropic efficiency' compares the actual energy change to some theoretical energy change under specified condition. Accordingly, isentropic efficiency of work producing or absorbing devices can be stated as:

$$\eta_s \equiv \begin{cases} \frac{W}{W_s} & \text{for work producing device} \\ \frac{W_s}{W} & \text{for work absorbent device} \end{cases} \quad (1)$$

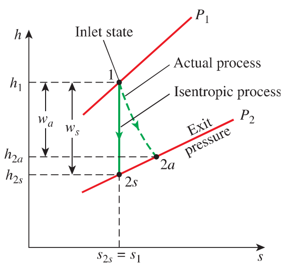
[5] B-Wark-1995.





- Thermal Efficiency, $\eta_{th} = \frac{W_{net}}{Q_{in}}$
- Isentropic Efficiency or First Law Efficiency, $\eta_s$

*Turbine*

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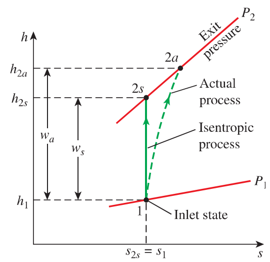
$$\eta_s = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

*Compressor*

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$$\eta_s = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$





## Energy: Quantity & Quality

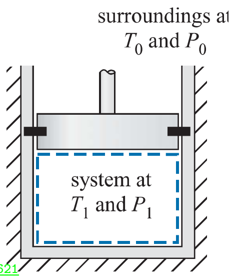
- *Quality of energy* is its potential to produce useful work.
- First Law of Thermodynamics:
  *energy is conserved in all (non-nuclear) processes.*
- Second Law of Thermodynamics:
  *the quality of energy is reduced in all real processes.*

⇒ During transformation and transfer, energy is both conserved and degraded.

⇒ Exergy is defined a the maximum work potential of a system at a given state as it proceeds towards a state of equilibrium with the environment while exchanging heat solely with environment[6].

[6] B-Wark-1995.

## Exergy Concept

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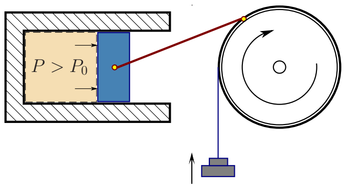


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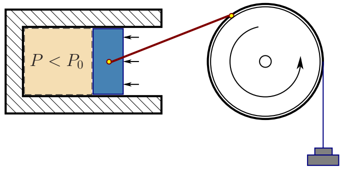


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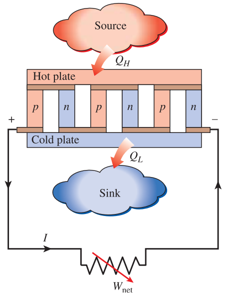
*When the pressure, temperature, composition, velocity, or elevation of a system is different from the environment, there is an opportunity to develop work.*





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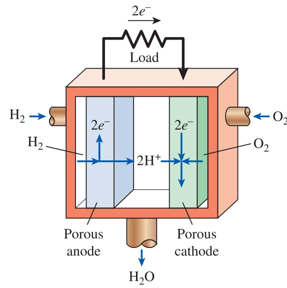


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*Standard atmosphere*

- $P_0 = 100$ kPa, $T_0 = 300$ K
- relative humidity, $\phi = 100\%$

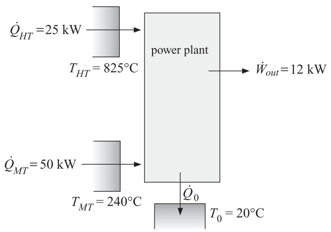
| Species | Mole fraction | Mass fraction |
|---|---|---|
| $N_2$ | 0.78084 | 0.75520 |
| $O_2$ | 0.20947 | 0.23143 |
| $Ar$ | 0.00934 | 0.01288 |
| $CO_2$ | 0.00031 | 0.00048 |





- Second Law Effectiveness, $\epsilon$ is an exergy based performance parameter[7]:

$$\epsilon \equiv \frac{\text{useful exergy out}}{\text{exergy in}} = 1 - \frac{\text{exergy destruction}}{\text{exergy in}}$$

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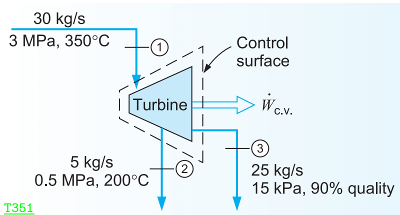
- $\eta_{th} = \frac{W_{out}}{Q_{HT}+Q_{MT}} = \frac{12}{25+50} = 16\%$
- $\Phi_{Q,HT} = 25\left(1 - \frac{293}{1098}\right) = 18.33$
- $\Phi_{Q,MT} = 50\left(1 - \frac{293}{513}\right) = 21.44$
- $\epsilon = \frac{W_{out}}{E_{x,Q,HT}+E_{x,Q,MT}} = 30.2\%$

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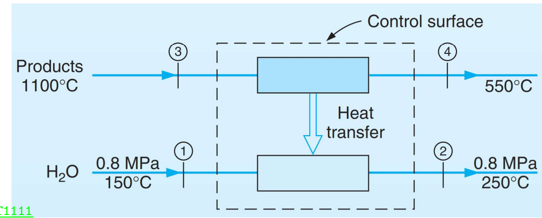
- $\eta_{th} = 79.9\%$
- $\epsilon = 81.9\%$

[7] B-Moran-1989.





## Exergy Loss in a Boiler without Heat-Loss

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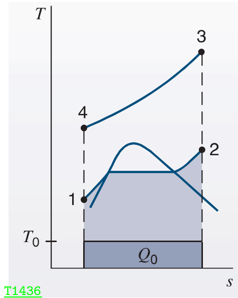


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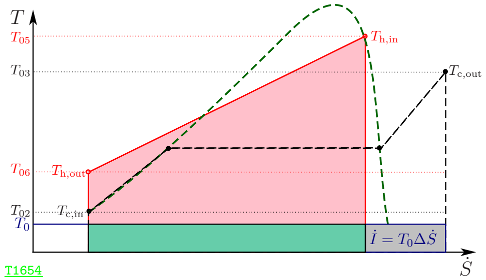
- $\frac{m_{gas}}{m_{water}} = \left[\frac{h_2 - h_1}{h_3 - h_4}\right] = 3.685$ kg/kg
- $\eta = 100\%$, as no heat is lost.
- $\epsilon = \frac{m_{gas}(\psi_2 - \psi_1)}{m_{water}(\psi_3 - \psi_4)} = 45.8\%$.

## Exergy is Destroyed in Heat-Transfer

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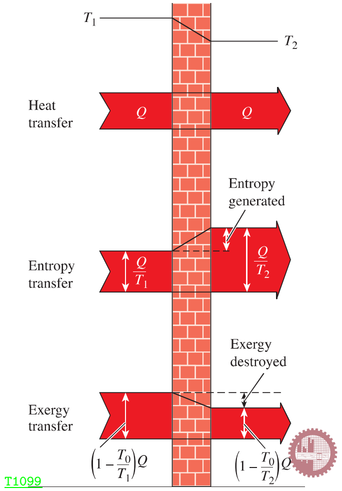


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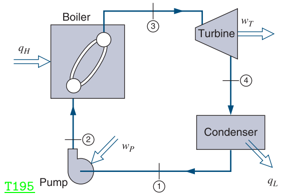
## Effect of Super-heating Steam to Higher Temperature

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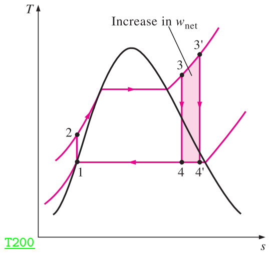


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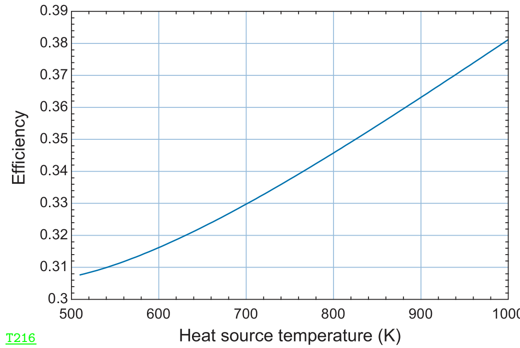


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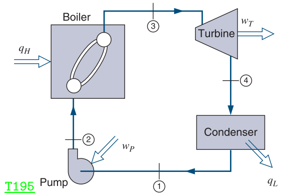
## Effect of Increasing Boiler Pressure

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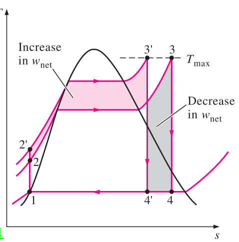


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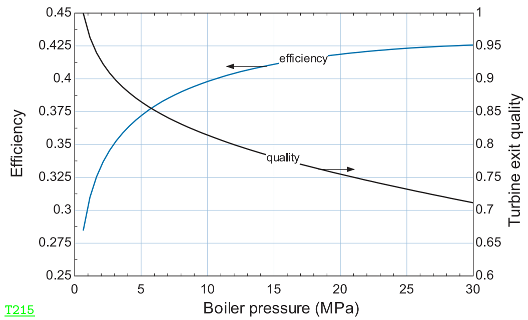


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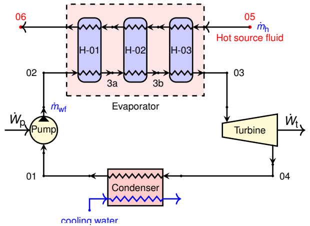
## Performance Parameters of a WHR system[8]

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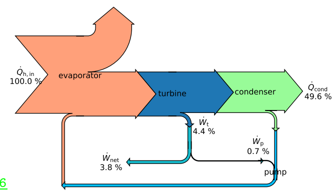


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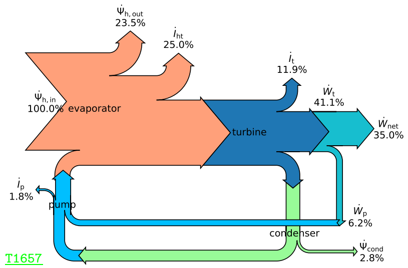


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- $\eta_{th} = 3.8\%$,
- $\epsilon = 35.0\%$.

[8] 6000.

# Thanks a Lot